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16 May 1961

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P-2310

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In a document published several months ago entitled: "Factors Affecting Degree of Automation in Test and Checkout Equipment" which, among other things, reviews the problems of allocation of functions, Swain and Wohl assert:

". . .A rather stark conclusion emerges: There is no adequate systematic methodology in existence for allocating functions (in this case, test and checkout functions) between man and machine. This lack, in fact, is probably the central problem in human factors engineering today. . . .It is interesting to note that ten years of research and applications experience have failed to bring us closer to our goal than did the landmark article by Fitts in 1951."(5, p.3) These two competent and experienced observers summarize ten years of hard and intensive labor as having basically failed. This is a serious problem. Why this failure?

We can attempt to seek a possible answer to the question by seeking a similar case in other fields of scientific endeavor and seeing what can be learned from it. And another case is easy to find; it is in fact a classical case. In their book: "The Evolution of Physics", Einstein and Infeld spend some time discussing the problems which beset pre-relativity physics in which they focus upon the concept of 'ether'. They point out that ether played a central role in physical thinking for over a century after having first been introduced as a necessary medium for propagating electromagnetic waves. But during all this time all attempts to build and expand upon this concept led to difficulties and contradictions. A century of research on ether turned out to be sterile in that no significant advance was made during that time.

They conclude: "After such bad experiences, this is the moment to forget ether completely and try never to mention its name."[3, p.184] And they do not mention the concept anymore in the book. The facts underlying the concept were not rejected however, and it was by focussing upon the _facts_ while rejecting the _concept_ that Einstein could solve the problems which bedeviled the physics of his day.

The lesson to be learned from this momentous episode is that when a scientific discipline finds itself in a dead end, despite hard and diligent work, the dead end should probably not be attributed to a lack of knowledge of facts, but to the use of faulty concepts which do not enable the discipline to order the facts properly. The failure of human factor engineering to advance in the area of allocation of functions seems to be such a situation. Hence, in order to find an answer to the question: "Why this failure?", it may be fruitful to examine the conceptual underpinnings of our contemporary attempts at allocating functions between men and machines. And this brings us back to the landmark article by Fitts mentioned earlier.[4]

This article gave rise to what is now informally called the 'Fitts list'. This is a two column list, one column headed by the word 'man' and the other, by the word 'machine'. It _compares_ the functions for which man is superior to machines to the functions for which the machine is superior to man. Theoretically this leads to an elegant solution to the allocation of functions. Given a complex man-machine system, identify the functions of the system and then, based on such a list which was expected to be refined with time and experience, choose machines for the functions they are best suited for and men for the functions they are best suited for. This is a clean engineering approach and it is not surprising that great hopes were placed upon it, in 1951. The only gimmick is that it did not and doesn't work.

The facts to be found in all the existing versions of the 'Fitts list' are all correct, just as the facts underlying the concept ether were all correct. Hence the inutility of these lists must be attributed to what we are told to do with these facts, to the instruction to compare man to the machine and choose the one who fits a function best. I question the comparability of men and machines. If men and machines are not comparable, then it is not surprising that we get nowhere when we try to compare them. Just as the concept of ether led to inutility, perhaps the concept of man-machine comparability does the same. Let us explore somewhat the background to the concept comparability.

The literature on the place of a man in man-machine systems converges to two posthumous articles by K. J. W. Craik published in 1947.[2] These articles are recognized by almost all as being the basis upon which much that followed is built. Craik argues that in order to best be able to plan, design, and operate a complex system man functions and machine functions should be described in the same concepts, and, by the very nature of the case, these concepts have to be engineering terms. In other words, Craik recommends that we describe human functions in mathematical terms comparable to the terms used in describing mechanical functions.

In fairness to Craik's memory it must be stressed that these two papers published after his death were notes for a discussion and probably not meant for publication. Hence he should not be blamed for failing to recognize the simple fact that anytime we can reduce a human function to a mathematical formula we can generally build a machine that can do it more efficiently than a man. In other words, to the extent that man becomes comparable to a machine we do not really need him any more since he can be replaced by a machine. This necessary consequence was actually reached but not recognized in a later paper, also a fundamental and significant paper in human factor engineering literature. In

1954 Birmingham and Taylor in their paper: "A Design Philosophy for Man-Machine Control Systems", write: ". . . **speaking** mathematically, he (man) is best when doing least."[1, p.1752] The conclusion is inescapable -- design the man out of the system. If he does best when he does least, the least he can do is zero. But then the conclusion is also ridiculous. Birmingham and Taylor found themselves in the same paradoxical situation in which Hume found himself some two hundred years earlier where his logic showed him that he could not know anything while at the same time he knew he knew a lot.

This contradiction, so concisely formulated oy Birmingham and Taylor yet not recognized by them or, **it seems, by their readers, should have served as** a warning that something was wrong with the conceptualization underlying the thinking in this area. But it didn't.

Now we can see why the 'Fitts lists' have been impotent. To the extent that we compare, numerically, human functions to machine functions we must reach the conclusion that wherever possible the machine should do the job. This may help to explain a curious aspect in designers' behavior which has annoyed some: an annoyance expressed trenchantly by a human factors engineer over a glass of beer thusly: "Those designers, they act as if they get a brownie point every time they eliminate a man."

Let us return to the 'Fitts lists'. They vary all over the place in length and in detail. But if we try to abstract the underlying commonalities in all of them we find that they really make one point and only one point. Men are flexible but cannot be depended upon to perform in a consistent **manner whereas machines can be depended upon to perform consistently but they have no flexibility** whatsoever. This can be summarized simply and seemingly tritely by saying that men are good at doing that which machines are not good

at doing and machines are good at doing that which men are not good at doing. Men and machines are not comparable, they are complementary. Gentlemen, I suggest that 'complementary' is probably the correct concept to use in discussing the allocation of tasks to men and to machines. Rather than compare men and machines as to which is better for getting a task done let us think about how we complement men by machines and vice versa to get a task done.

As soon as we start to think this way we find that we have to start thinking differently. The term 'allocation of tasks to men and machine' becomes meaningless. Rather we are forced to think about a task that can be done by men and machines. The concept 'task' ceases to be the smallest unit of analysis for designing man-machine systems though still remaining the basic unit in terms of which the analysis makes sense. The task now consists of actions, or better still activities, which have to be shared by men and machines. There is nothing strange about this. In industrial chemistry the molecule is the fundamental unit for many purposes and it doesn't disturb anybody that some of these molecules consist of hundreds, if not thousands, of atoms. The analysis of man-machine systems should therefore consist of specifications of tasks and activities necessary to accomplish the tasks. Man and machine should complement each other in getting these activities done in order to accomplish the task.

It is possible that with a shift to emphasizing man-machine comparability new formats for system analysis and design will have to be developed, and these formats may pose a problem. I am convinced however that as soon as we begin thinking in proper units this problem will be solved with relative ease. Regardless whether this is so, one can now already specify several general principles that may serve as basic guidelines for complementing men and machines.

Machines serve man in two ways: as tools and as production machines.
A tool extends man's ability, both sensory and motor; production machines
replace man in doing a job. The principle underlying the complementarity
of tools is as follows: Man functions best under conditions of optimum
difficulty. If the job is too easy he gets bored, if it is too hard he
gets fatigued. While it is generally silly to use machines to make a job
more difficult, although this may be exactly what is called for in some
control situations, tools have, since their inception as eolitns, served to
make a difficult job easier and an impossible job possible. Hence tools
should be used to bring the perceptual and motor requirements of a task to
the optimum levels for human performance. We have had a lot of experience
with tools and they present few, if any, problems.

The problem is more complex with machines that do a job in place of man.
Here we can return with benefit to the commonalities underlying the 'Fitts
lists'. To the extent that the task environment is predictable and a priori
controllable, and to the extent that activities necessary for the task are
iterative and demand consistent performance, a production machine is prefer-
able to man. To the extent, however, that the environment is not predictable,
or if predictable not controllable a priori, then man, aided by the proper
tools, is required. It is in coping with contingencies that man is irreplaceable
by machines. This is the essential meaning of human flexibility.

Production machines pose a problem rarely posed by tools since they
replace man in doing a job. They are not perfect and tend to break down.
When they break down they do not do the job. One must always then take into
account the criticality of the job for the system. If the job is critical, the
system should so be designed that man can serve as a manual backup to the

machine. Although he will then not do it as well as the machine, he still can do it well enough to pass muster. This is another aspect of human flexibility -- the ability for graceful degradation. Machines can either do the job as specified or they botch up; man degrades gracefully. This is another example of complementarity.

Planning for feasible manual backup is a difficult job in the contemporary complex systems that we are constructing. It has generally been neglected. In most simple systems explicit planning is not necessary since man's flexibility is generally adequate enough to improvise when the relatively simple machines break down. But this changes with growing system complexity.

It is here that 'automation' should be mentioned. Some of you may have been bothered by the fact that 'automation' is in the title of this paper but has, as yet, still to be introduced. The reason is rather simple. Although automation represents a significant technological breakthrough which has generated many specific problems, the allocation of tasks to men and machines being one of them, conceptually, an automated machine is just another machine, albeit radically different in its efficiency and performance characteristics. The problems that were generally latent or not too critical in the older, simpler man-machine systems became both manifest and critical, however, with its introduction. One of the most critical areas is manual backup.

We customarily design automated systems by allocating those functions which were either difficult or too expensive to mechanize to man and the rest to machines. As many articles in the literature indicate, we have looked upon man as a link in the system and have consequently given him only the information and means to do the job assigned to him as a link. When the system

breaks down a man in a link position is as helpless as any other machine
component in the system. We have tended to design out his ability to take
over as a manual backup to the system. At the same time the jobs performed
by the machine have become more and more important and the necessity for a
manual backup consequently greater. How to design a complex automated system
to facilitate its being backed up manually is a neglected area. One thing
seems certain. It will most probably call for 'degradation' in design, that
is, systematically introducing features which would not have been necessary
were no manual backup needed. This is an important area for future human
factors engineering research.

Another area of complementarity which is gaining in significance as the
systems are getting more and more complex is that of responsibility. Assuming
we lick the problems of reliability we can depend upon the machines to do
those activities assigned to them consistently well, but we never can assign
them any responsibility for getting the task done; responsibility can be
assigned to men only. For every task, or for every activity entailed by the
task, there must be a man who has the assigned responsibility to see that the
job be done as efficiently as warranted. This necessitates two things: the
specification of clear cut responsibilities for _every_ man in the system and
supplying the men with means which will enable them to exercise effective
control over those system tasks and activities for which they are responsible.
You may think that this is obvious -- yes it is. But it is surprising how
rare, and then how ineffective, our planning and design in this area are.
Experience to date with automated systems shows that the responsibilities
of the individuals involved are generally nebulous so that when something
unexpected occurs people often do not know who is to do what. Even to the

extent that these responsibilities are clarified with time and experience, the system hardware often makes it difficult for men to assume these responsibilities, the means for man to exercise control over the areas of his responsibility being either inadequate or lacking.

The complementarity of men and machines is probably much more profound and suotle than these aspects which I have just high-lighted. Many other aspects will undoubtedly be identified, elaborated, and ordered to the extent that we start thinking about how one complements the other. In other words, to the extent that we start humanizing human factors engineering. It is not surprising that the ten years of lack of progress pointed to by Swain and Wohl were accompanied by the conceptual definition of treating man as a machine component. Man is not a machine, at least not a machine like the machines men make. And this brings me to the last point I would like to make in this paper.

When we plan to use a machine we always take the physical environment of the machine into account; that is: its power supply, its maintenance requirements, the physical setting in which it has to operate, etc. We have also taken the physical environment of man into account, to a greater or lesser extent; that is: illumination and ventilation of the working area, noise level, physical difficulties, hours of labor, coffee breaks, etc. But a fundamental difference between men and machines is that men also have a psychological environment for which an adequate physical environment is a necessary condition but is ultimately secondary in importance. This is the truth embedded in the adage: Man does not live by bread alone. The psychological environment is subsumed under one word: 'motivation'. And the problems of human motivation are at present eschewed by human factors engineering.

You can lead a horse to water but cannot make him drink. In this respect a man is very similar to a horse. Unless the human operator is motivated he will not function as a complement to machines, and the motivation to function as a complement must be embedded within the task itself. Unless a task represents a challenge to the human operator he will not use his flexibility or his judgment, he will not learn nor will he assume responsibility, nor will he serve efficiently as a manual backup. By designing man-machine systems for man to do least we also eliminate all challenge from the job. We must clarify to ourselves what it is that makes a job a challenge to man, and build in those challenges in every task, and activity, and responsibility which we assign to the human operator. Otherwise man will not complement the machines but will begin to function like a machine.

And here too men differ significantly from machines. When a man is forced to function like a machine he realizes that he is being used inefficiently and he experiences it as his being used stupidly. And men cannot tolerate such stupidity. Overtly or covertly men resist and rebel against it. Nothing could be more inefficient and self-defeating in the long run than the construction of man-machine systems which cause the human components in the system to rebel against the system.

Herein lies the main future challenge to human factors engineering.

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